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# DEFINING THE NEWBORN PIGLET'S THERMAL ENVIRONMENT WITH AN EFFECTIVE ENVIRONMENTAL TEMPERATURE

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**ABSTRACT.** *An effective environmental temperature (EET) developed for newborn piglets describes the thermal environment by incorporating the mean radiant temperature, dry-bulb temperature, and air velocity near the newborn. The adequacy of the defined EET was analyzed by comparing with three published studies on newborn sensible heat loss. Results from the published studies indicate that the EET predicted between 87% and 98% of the variability in the data.*  
**Keywords.** *Heat loss, Piglet, Ventilation.*

A newborn piglet (less than one week old) is exposed to environmental conditions substantially different from the embryonic environment to which it was accustomed. Neonatal survival is a function of many factors, one being the quality of the thermal environment. Minimizing cold stress and maintaining a newborn's thermal environment within an acceptable range increases the survival rate and growth. Cold stress occurs when energy needed for growth and survival is diverted to maintain homeothermy. Research on newborns indicates that radiative and convective heat loss accounts for almost 90% of the total loss (Mount, 1964a). By controlling parameters that affect heat loss, newborn heat loss can be maintained at acceptable levels and energy preserved for body maintenance and growth.

A newborn's thermal environment often is defined only in terms of the dry-bulb temperature. This condition is valid only for farrowing rooms which have well-insulated walls, ceilings, and floors, low air velocities that produce natural convection, and uniform environmental conditions throughout the space. However, many farrowing facilities deviate substantially from the ideal conditions. A single index that describes the effective thermal environment for non-ideal farrowing rooms would be useful.

The objective of this article is to define an effective environmental temperature (EET) using measurable or known quantities that correlate with the heat loss from newborns in various radiative and convective environments. The effectiveness of the EET developed is

demonstrated with results from past calorimetric studies on newborn heat loss (Mount, 1964a; Butchbaker and Shanklin, 1964; and Mount, 1966). A high correlation between the EET and measured heat loss would indicate that the defined EET incorporates the most important parameters needed to describe a newborn's thermal environment. The EET can be used to identify strategies for maintaining a newborn's environment within ranges conducive to survival and optimum growth.

## LITERATURE REVIEW

Numerous attempts have been made to develop a single index which describes the thermal environment for animals. Beckett (1965) developed a swine effective temperature (SET) based on the physiological response of 70 kg pigs to dry bulb air temperature and relative humidity. The SETs for various dry bulb temperatures (TDB) and moisture conditions were defined when they produced the same physiological response (measured as the amount of air breathed per unit time) as the actual environment. The SET has no provisions for incorporating the effects of surrounding surface temperatures and air velocity near the animal.

Mount (1975) attempted to describe the thermal environment of growing pigs (20-55 kg) with an equivalent standardized environmental temperature (ESET). The standardized environment was described as a structure that was well-insulated, had air velocities that resulted only in natural convection, and had insulated floors. The ESET was the dry-bulb temperature in the standardized environment that produced the same heat loss as the actual environment. The ESET results were based on values calculated for humans from Burton and Edholm (1955). Mount's description, unlike Beckett's (1965), took into consideration surrounding surface temperatures, air velocity near the animal, floor conditions, and the actual TDB. The results, however, were based on human parameters and extrapolated to newborn piglets.

Curtis (1983) summarized the findings of Mount (1975) and devised a technique for correcting the dry bulb air temperature based on air velocity, bedding arrangement, and surface-air temperature differences. Curtis (1983)

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formulated these thermal effects into dry bulb air temperature reductions. The corrected effective environmental temperature was intended to describe the thermal demand of the environment on groups of young pigs. Limited discrete temperature adjustments are provided.

ASHRAE (1989) defines the operative temperature for humans as (see nomenclature for variable definitions):

$$T_o = \frac{(h_r T_{MRT} + \bar{h}_c TDB)}{h_r + \bar{h}_c} \quad (1)$$

By definition, the operative temperature is the uniform temperature of an imaginary enclosure in which an animal will exchange the same sensible heat by radiation and convection as in the actual environment. Equation 1 requires the determination of the radiative coefficient ( $h_r$ ) which in turn requires a knowledge of the newborn's skin surface temperature. A more serious drawback to the operative temperature is for an environment in which the mean radiant temperature (MRT) is equal to the TDB; the resulting  $T_o$  is equal to the TDB (or MRT) because the convective and radiative coefficients cancel. Therefore, even at high velocities, no adjustments will be made to the resulting effective temperature.

In an attempt to simplify the description of the environment, ASHRAE (1989) has defined an alternative to the operative temperature. This description is called the adjusted dry bulb temperature (ADBT) and is expressed as:

$$T_{ADBT} = \frac{T_{MRT} + T_\infty}{2} \quad (2)$$

The ADBT is intended as a practical estimate of the operative temperature. It describes the combined effects of dry bulb temperature and temperatures of the surrounding surfaces.

## THE EET DEVELOPMENT

The evaporative and conductive losses are assumed negligible. This assumption was made based on the calorimetry work reported by Mount (1964a), Butchbaker and Shanklin (1964), and Mount (1966).

Mount (1964a) studied the radiative, convective and evaporative heat losses from newborns and found that the evaporative portion of the heat loss accounted for 6% to 13% of the total heat loss. Butchbaker and Shanklin (1964) reported that the evaporative heat loss was small, accounting for about 8% of the total heat loss (radiative, convective, and evaporative). Mount (1967) studied the partitional heat loss of a newborn. He found that evaporation and conduction losses of newborns lying on bare concrete accounted for 28% of the total at a TDB of 30.0° C and 9% at environmental temperatures (TDB) of 20.0° C with an insulated floor.

The assumption of negligible evaporative heat loss is invalid as dry-bulb temperature approaches the core temperature of the animal and conductive heat loss becomes large when the newborn lies on bare concrete at a

temperature below the newborn's core temperature. Therefore, the defined EET is restricted to an upright newborn, subjected to a dry-bulb temperature less than 30° C.

The effective environmental temperature (EET) for newborns is based on three parameters; the mean radiant temperature (MRT), dry-bulb temperature (TDB), and air velocity. EET development uses a sensible heat balance to describe convective heat loss, and uses MRT to describe the radiative heat loss.

The EET defined here attempts to incorporate the simplicity of the ADBT with the expanded environmental knowledge of the operative temperature. Two of the three primary parameters needed in the EET are included in the ADBT. However, the velocity of the air moving over the newborn's surface is missing. To incorporate air velocity, a term analogous to the MRT was defined. The term, modified ambient temperature (MAT), describes the convective environment and includes both dry bulb temperature and air velocity over the newborn. In equation form, the EET is:

$$T_{EET} = \frac{T_{MRT} + T_{MAT}}{2} \quad (3)$$

Two underlying assumptions to the EET defined in equation 3 are that the radiative and convective environments each contribute 50% to the heat loss from the newborn and the radiative and convective environments can be described independently of each other without serious error.

### MEAN RADIANT TEMPERATURE (MRT)

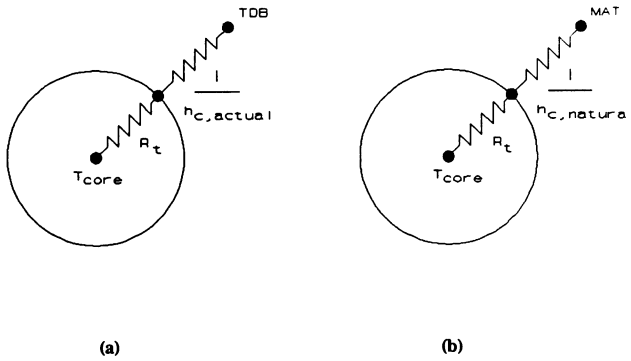
The mean radiant temperature (MRT) is defined as the uniform surface temperature of an imaginary black enclosure with which a person (or newborn pig), also assumed to be a black body, exchanges the same heat by radiation as in the actual environment (McQuiston and Parker, 1982). The MRT in degree centigrade is (ASHRAE, 1989):

$$T_{MRT} = \left[ \sum_{n=1}^m T_{n, \text{ absolute}}^4 F_{\text{newborn} - n} \right]^{0.25} - 273.2 \quad (4)$$

To calculate the MRT, the surrounding surface temperatures must be known as well as the shape factors between the newborn and those surfaces at their respective temperatures. An alternative approach is to directly measure the MRT with a two-sphere radiometer (ASHRAE, 1989).

### MODIFIED AMBIENT TEMPERATURE (MAT)

The MAT is defined as the equivalent temperature of a naturally convective environment that results in the same convective heat loss as in the actual environment. The MAT can be illustrated through an analysis of a thermal resistance model. Figure 1 defines the convective situation for the actual and modified environments, respectively. To find the relationship that defines the MAT, the heat transfer



**Figure 1—Convection heat loss assumption between actual and modified environment used to describe the MAT.**

in figure 1a must be equal to the heat transfer in figure 1b. Equating both heat transfer expressions results in:

$$\left[ \frac{(T_{\text{core}} - T_{\text{DB}})}{\left( R_t + \frac{1}{h_{c, \text{actual}}} \right)} \right] = \left[ \frac{(T_{\text{core}} - T_{\text{MAT}})}{\left( R_t + \frac{1}{h_{c, \text{natural}}} \right)} \right] \quad (5)$$

Solving this expression for the MAT results in:

$$T_{\text{MAT}} = T_{\text{core}} \left[ 1 - \frac{\left( R_t + \frac{1}{h_{c, \text{natural}}} \right)}{\left( R_t + \frac{1}{h_{c, \text{actual}}} \right)} \right] + T_{\text{DB}} \left[ \frac{\left( R_t + \frac{1}{h_{c, \text{natural}}} \right)}{\left( R_t + \frac{1}{h_{c, \text{actual}}} \right)} \right] \quad (6)$$

#### EFFECTIVE ENVIRONMENTAL TEMPERATURE (EET)

The effective environmental temperature (EET) is obtained by substituting equations 4 and 6 into equation 3. The resulting expression is:

$$T_{\text{EET}} = \frac{\left[ \sum_{n=1}^m T_{n, \text{absolute}}^4 F_{\text{newborn} - n} \right]^{0.25} - 273.2 + T_{\text{core}} \left[ 1 - \frac{\left( R_t + \frac{1}{h_{c, \text{natural}}} \right)}{\left( R_t + \frac{1}{h_{c, \text{actual}}} \right)} \right] + T_{\text{DB}} \left[ \frac{\left( R_t + \frac{1}{h_{c, \text{natural}}} \right)}{\left( R_t + \frac{1}{h_{c, \text{actual}}} \right)} \right]}{2} \quad (7)$$

#### THE EET FOR NEWBORNS

The EET (eq. 7) can be calculated when the governing parameters associated with the newborn and its thermal environment have been specified. Parameters associated with the newborn are tissue resistance and convective coefficients in both naturally and forced convective

**Table 1. Core-to-skin thermal resistance as a function of dry-bulb temperature (Mount, 1964b)**

TDB (C)	$R_t$ (C-m <sup>2</sup> / W)	% Difference*
5.0	0.043	30.3
22.0	0.034	3.0
20.0	0.026	- 21.2
33.0	0.017	- 48.5
35.0	0.009	- 72.7
38.0	0.0	- 100.0

\* Compared to assumed average value of 0.033 C-m<sup>2</sup> / W.

environments. These parameters are, in turn, dependent on environmental conditions to which the newborn is exposed.

#### TISSUE RESISTANCE

Tissue resistance for EET development was defined as the thermal resistance present between the inner core and skin surface of the newborn. Total resistance includes thermal resistance of the newborn's tissue composition and convective resistance encountered when energy is transferred by blood flow to the skin surface through vascular channels. This latter component of total resistance is environmentally dependent. Newborns have the ability to constrict or dilate blood vessels when environmentally stressed.

Research results from Mount (1964b) were used to estimate newborn tissue resistance. Results from Mount (1964b) are presented in table 1. Measurements were taken in a chamber where wall temperatures were equal to air temperatures and velocity levels were at still air (< 0.12 m/s) conditions. For this analysis, the average value ( $R_t = 0.033 \text{ m}^2\text{-C/W}$ ) was used.

#### CONVECTIVE COEFFICIENTS

Newborn's can encounter either a naturally convective environment (equivalent still-air conditions) or a forced convective environment. Empirical relations presented in Holman (1981) for natural and forced convection from a cylinder were used. For natural (or free) convection, the following expression was used:

$$h_{c, \text{natural}} = \frac{k_f}{D} \left[ 0.36 + \frac{0.518 (Gr_d Pr)^{0.25}}{\left[ 1 + \left( \frac{0.559}{Pr} \right)^{9/16} \right]^{4/9}} \right] \quad (8)$$

In a similar manner, for forced convection, the expression for the convective coefficient for flow normal to the central axis of a cylinder was used:

$$h_{c, \text{forced}} = \frac{k_f}{D} 0.683 \left[ \frac{U_\infty D}{\nu_f} \right]^{0.466} \text{Pr}^{1/3} \quad (9)$$

Calculation of convection coefficients requires specifying the cylinder diameter (D) used to model the newborn as well as the air conductivity ( $k_f$ ), Prandtl number (Pr), kinematic viscosity ( $\nu_f$ ), density ( $\rho$ ), and Grashof number ( $Gr_d$ ).

The cylinder diameter used to model the newborn was determined using results in MWPS (1983). From MWPS, the estimated depth (bottom of belly to top of back) and width (across shoulders or hams) of a newborn was 7.6 and 6.4 cm, respectively. For this analysis, a characteristic dimension of 7.6 cm was used to estimate the newborn's width. The characteristic dimension describing newborn length was determined from a surface area balance. Assuming 1.6 kg at birth, the total newborn surface area estimated from Brody's (1945) equation is 0.13 m<sup>2</sup>. Using the estimated surface area (0.13 m<sup>2</sup>) and characteristic diameter (7.6 cm), the characteristic length (excluding cylinder ends) is 55 cm. A cylinder 7.6 cm in diameter and 55 cm long was used to simulate the size and surface area of the newborn pig. The results are similar to the technique employed by Bruce and Clark (1979).

The Grashof number based on the modeled cylinder,  $Gr_d$ , is defined as (Holman, 1981):

$$Gr_d = \frac{g \beta (T_{\text{newborn}} - \text{TDB}) D^3}{\nu_f^2} \quad (10)$$

$$T_{\text{EET}} = \frac{\left[ \sum_{n=1}^m T_{n, \text{absolute}}^4 F_{\text{newborn} - n} \right]^{0.25} - 273.2 + T_{\text{core}} \left[ 1 - \frac{A}{B} \right] + \text{TDB} \frac{A}{B}}{2} \quad (14)$$

The film temperature used to determine kinematic viscosity ( $\nu_f$ ) is defined as (Holman, 1981):

$$T_f = \frac{T_{\text{newborn}} + \text{TDB}}{2} \quad (11)$$

Incorporating the estimated surface temperature ( $T_{\text{newborn}}$ ) of 34° C and a dry bulb temperature (TDB) of 18° C resulted in a film temperature of 26° C. The film temperature also was also used to determine the air conductivity ( $k_f$ ) and the Prandtl number (Pr). From Holman (1981), these parameters become:

$$\begin{aligned} k_f &= 0.026 \text{ W/(m}\cdot\text{C)} \\ \nu_f &= 15.6 \times 10^{-6} \text{ m}^2/\text{s} \\ \text{Pr} &= 0.708 \end{aligned}$$

These parameters will vary as the dry-bulb temperature and newborn surface temperature deviate from the values specified above. The changes in the assumed film temperature of 26° C will be relatively small and thus will not substantially affect the air conductivity, kinematic viscosity, and Prandtl Number.

The volumetric coefficient of expansion ( $\beta$ ) for ideal gases is defined as the inverse of the absolute temperature of the gas. Using the same average dry bulb temperature, 18° C, volumetric coefficient of expansion was 0.0034/K. Substituting necessary components into equation 10 resulted in a Grashof number of  $9.81 \times 10^5$ . Natural and forced convective coefficients were then estimated to be:

$$h_{c, \text{natural}} = 4.01 \frac{W}{\text{m}^2 - \text{C}} \quad (12)$$

$$h_{c, \text{forced}} = 10.94 U_\infty^{0.466} \frac{W}{\text{m}^2 - \text{C}} \quad (13)$$

The velocity at which forced convection begins to dominate convective heat loss can be estimated if equations 12 and 13 are equated. The resulting velocity is 0.12 m/s. At free stream air velocities below 0.12 m/s, natural convection dominates, and the convective coefficient was assumed to be constant at 4.01 W/m<sup>2</sup>-C. For velocity levels at and above 0.12 m/s, equation 13 was used to estimate the convective coefficient. Hoff (1987) provides a more detailed convection analysis.

Substituting equations 12 and 13, and estimated tissue resistance ( $R_t = 0.033 \text{ m}^2\cdot\text{C/W}$ ) in equation 7 results in the completed EET expression for a single newborn:

where

$$\begin{aligned} A &= 0.2824 \frac{\text{m}^2 - \text{C}}{W} \\ B &= \left( 0.033 + \frac{0.0914}{U_\infty^{0.466}} \right) \frac{\text{m}^2 - \text{C}}{W} \end{aligned}$$

Newborn core temperature,  $T_{\text{core}}$ , in equation 14 was assumed to be constant and equal to 39.5° C. This value was based on Mount's (1964a and 1964b) work and information from MWPS (1983).

## RESULTS AND DISCUSSION

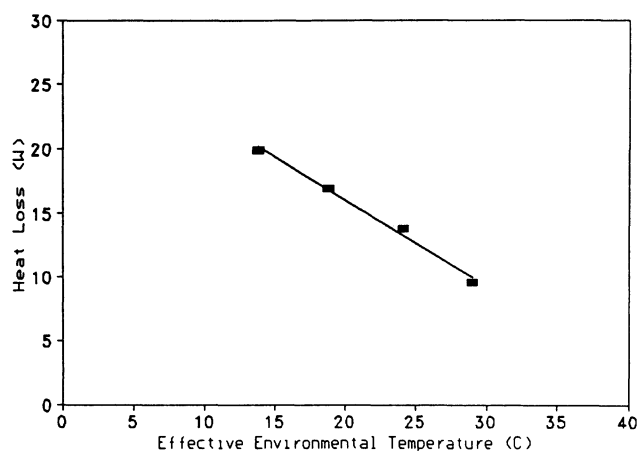
### EET vs. EXISTING HEAT LOSS DATA

Table 2 lists the MRT, TDB, air velocity, and measured heat loss rates conducted by Mount (1964a), Butchbaker and Shanklin (1964) and Mount (1966) that relate thermal environment to sensible heat loss of newborn pigs. The EET for each case was calculated using equation 14. Figures 2 through 5 are plots of EET versus heat loss

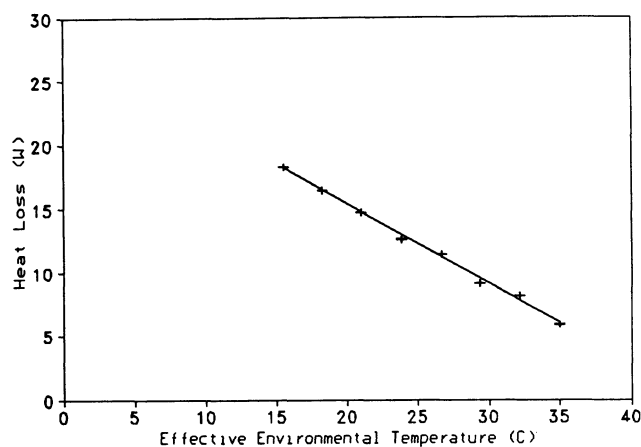
**Table 2. Calculated EET and measured newborn sensible heat loss data from three calorimetric studies**

Reference	$T_{MRT}$ (C)	TDB (C)	U (m / s)	$T_{EET}$ (C)	$Q^*$ (W)
Mount (1964a)	29.3	29.8	0.15	29.0	9.6
	19.2	30.1	0.15	24.1	13.8
	19.4	20.3	0.15	18.8	17.0
	9.7	20.1	0.15	13.8	19.9
Butchbaker and Shanklin (1964)	15.6	15.6	< 0.12	15.6	18.2
	18.3	18.3	< 0.12	18.3	16.4
	21.1	21.1	< 0.12	21.1	14.7
	23.9	23.9	< 0.12	23.9	12.6
	26.7	26.7	< 0.12	26.7	11.4
	29.4	29.4	< 0.12	29.4	9.1
	32.2	32.2	< 0.12	32.2	8.2
	35.0	35.0	< 0.12	35.0	5.9
Mount (1966)	20.0	20.0	< 0.12	20.0	16.5
	20.0	20.0	0.34	14.8	18.8
	20.0	20.0	0.82	9.1	17.8
	20.0	20.0	1.58	4.0	21.6
	30.0	30.0	< 0.12	30.0	10.0
	30.0	30.0	0.34	27.5	11.3
	30.0	30.0	0.82	24.7	10.8
	30.0	30.0	1.58	22.2	15.4

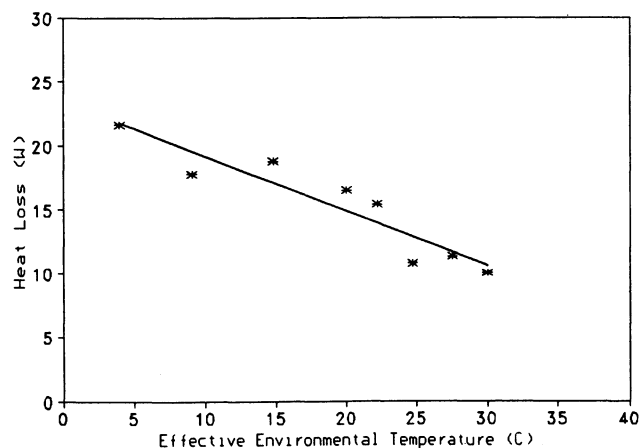
\* Reported heat loss.



**Figure 2—EET vs. heat loss from Mount's (1964a) calorimetric data.**



**Figure 3—EET vs. heat loss from Butchbaker and Shanklin's (1964) calorimetric study.**



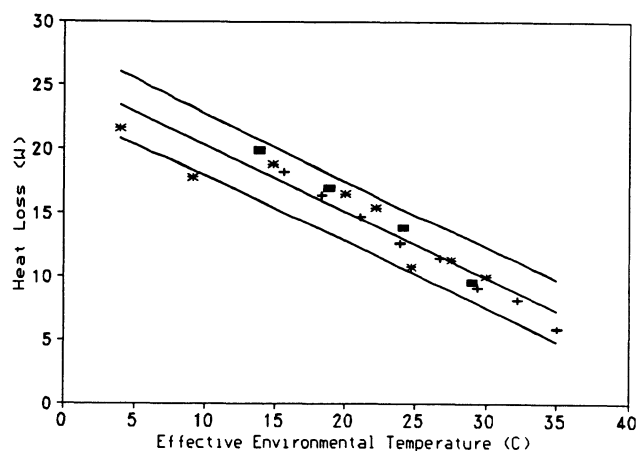
**Figure 4—EET vs. heat loss for Mount's (1966) calorimetric study.**

results for three studies with corresponding regression equations summarized in table 3.

Mount (1964a) investigated change in sensible heat loss from newborns for different MRT and TDB. Air velocity was held constant at 0.15 m/s. A regression between experimentally determined sensible heat loss and EET defined by equation 14 resulted in a coefficient of determination of 0.98. Figure 2 shows a plot of the regression and Mount's (1964a) data. EET ranged between 13.8° C and 29.0° C with a corresponding sensible heat loss ranging from 19.9 to 9.6 W.

Butchbaker and Shanklin (1964) studied the change in sensible heat loss due to variation in TDB in a well-insulated, naturally convective environment. Because the calorimeter was well-insulated, it was assumed that MRT was equal to TDB. Under these conditions, calculated EET equals TDB. The regression and data from Butchbaker and Shanklin are shown in figure 3. The coefficient of determination was 0.98. EET ranged from 15.6° to 35.0° C while sensible heat loss ranged from 18.2 to 5.9 W.

Mount (1966) investigated the effect of air velocity on sensible heat loss in a well-insulated chamber at 20.0° C and 30.0° C TDB. At each TDB level, velocity varied from



**Figure 5—EET vs. heat loss for the combined data set from (■) Mount (1964a), (+) Butchbaker and Shanklin (1964), and (\*) Mount (1966). Note: Upper and lower bands indicate 90% confidence interval.**

Table 3. Regression equations for figures 2 to 5

Reference	Figure	Regression Equation	$r^2$
Mount (1964a)	2	$Q = 29.4 - 0.67 * EET$	0.98
Buttbaker and Shanklin (1964)	3	$Q = 27.8 - 0.62 * EET$	0.98
Mount (1966)	4	$Q = 23.5 - 0.43 * EET$	0.87
All Data	5	$Q = 25.5 - 0.52 * EET$	0.91

still-air conditions (< 0.12 m/s) to forced conditions (0.34, 0.82, and 1.58 m/s). EET ranged from 4.0° to 30.0° C with corresponding sensible heat losses of 21.6 to 10.0 W, respectively. The resulting regression produced a coefficient of determination of 0.87 (fig. 4). Compared with previous studies (Mount, 1964a; Buttbaker and Shanklin, 1964), the correlation was not as high as studies where the velocity level was held at near still-air conditions.

The poorer correlation ( $r^2 = 0.87$ ) with Mount's (1966) study points out a weakness common to analytically based descriptions of newborn sensible heat loss. Under certain thermally stressing environmental conditions, animals engage in physiological responses to decrease heat lost. Physiological responses observed were vasoconstriction, pilo-erection, and postural changes (Mount, 1966). All three of these physiological responses are well-developed at birth (Mount, 1963b). The mathematical description presented here, based on an inert cylindrical model, is less descriptive of the heat loss from a physiologically responding newborn in a forced convective environment.

The physiological responses of newborn pigs become evident by comparing the regression equations for the data presented in figures 2, 3, and 4 and table 3. Mount (1964a) and Buttbaker and Shanklin (1964) (figs. 2 and 3) held their velocity at near still-air conditions. The resulting slopes ( $-0.62$  or  $-0.67$ , table 3) and intercepts between 27.8 and 29.4 W were similar (Mount, 1966; fig. 4). When the air velocity was varied from still-air to forced convective levels, the slope was  $-0.43$  and the intercept was 23.5 Watts. The differences in slope ( $-0.43$  vs.  $-0.62$  or  $-0.67$ ) and intercept (23.5 vs. 27.8 or 29.4) indicate a reduction in heat loss at lower EET levels. This implies that newborn pigs from Mount's (1966) study engaged in physiological responses as air velocity was increased.

Figure 5 summarizes the combined data set from figures 2 to 4 with the resulting regression equation shown in table 3. A substantial portion of the variation in the data set is described by the regression relation shown as evidenced by the high coefficient of determination ( $r^2 = 0.91$ ). In general, with the limited calorimetric studies presented, EET described by equation 14 appears to incorporate significant parameters that combine to define the newborn's heat loss.

## PRACTICAL USE OF THE EET

Table 4 presents calculated EET values as a function of dry bulb air temperature, mean radiant temperature, and free stream draft velocity using equation 14. The TDB ranged from 10.0° to 35.0° C. For each listed TDB, MRT

Table 4. Effective environmental temperature as a function of the dry-bulb temperature, mean radiant temperature, and air velocity\*

TDB (C)	$T_{MRT}$ (C)	Air Velocity							
		0.12 (m/s)	0.22 (m/s)	0.32 (m/s)	0.42 (m/s)	0.52 (m/s)	0.62 (m/s)	0.72 (m/s)	
10.0	5.0	7.3	3.2	0.1	-2.3	-4.3	-6.0	-7.6	
10.0	7.5	8.5	4.4	1.4	-1.0	-3.0	-4.8	-6.4	
10.0	10.0	9.8	5.7	2.6	0.2	-1.8	-3.5	-5.1	
10.0	12.5	11.0	6.9	3.9	1.5	-0.5	-2.3	-3.9	
10.0	15.0	12.3	8.2	5.1	2.7	0.7	-1.0	-2.6	1
15.0	10.0	12.3	8.9	6.4	4.4	2.7	1.2	0.0	
15.0	12.5	13.6	10.1	7.6	5.6	4.0	2.5	1.2	
15.0	15.0	14.8	11.4	8.9	6.9	5.2	3.7	2.5	
15.0	17.5	16.1	12.6	10.1	8.1	6.5	5.0	3.7	
15.0	20.0	17.3	13.9	11.4	9.4	7.7	6.2	5.0	
20.0	15.0	17.4	14.6	12.6	11.0	9.7	8.5	7.5	
20.0	17.5	18.6	15.9	13.9	12.3	11.0	9.8	8.8	
20.0	20.0	19.9	17.1	15.1	13.5	12.2	11.0	10.0	
20.0	22.5	21.1	18.4	16.4	14.8	13.5	12.3	11.3	
20.0	25.0	22.4	19.6	17.6	16.0	14.7	13.5	12.5	
25.0	20.0	22.4	20.4	18.9	17.7	16.7	15.8	15.1	
25.0	22.5	23.6	21.6	20.1	19.0	18.0	17.1	16.3	
25.0	25.0	24.9	22.9	21.4	20.2	19.2	18.3	17.6	
25.0	27.5	26.1	24.1	22.6	21.5	20.5	19.6	18.8	2
25.0	30.0	27.4	25.4	23.9	22.7	21.7	20.8	20.1	
30.0	25.0	27.4	26.1	25.1	24.4	23.7	23.1	22.6	
30.0	27.5	28.7	27.3	26.4	25.6	25.0	24.4	23.9	
30.0	30.0	29.9	28.6	27.6	26.9	26.2	25.6	25.1	
30.0	32.5	31.2	29.8	28.9	28.1	27.5	26.9	26.4	
30.0	35.0	32.4	31.1	30.1	29.4	28.7	28.1	27.6	
35.0	30.0	32.5	31.8	31.4	31.0	30.7	30.4	30.2	
35.0	32.5	33.7	33.1	32.6	32.3	32.0	31.7	31.4	Preferred
35.0	35.0	35.0	34.3	33.9	33.5	33.2	32.9	32.7	
35.0	37.5	36.2	35.6	35.1	34.8	34.5	34.2	33.9	
35.0	40.0	37.5	36.8	36.4	36.0	35.7	35.4	35.2	2

\* "1" corresponds to extreme cold stress, "2" corresponds to Zone I (fig. 7), and "preferred" corresponds to Zone II (fig. 7).

was varied about TDB by  $\pm 2.5^\circ$  C and velocity ranged from 0.12 to 0.72 m/s in 0.10 m/s increments. Table 4 has included MRT values above the respective TDB values for

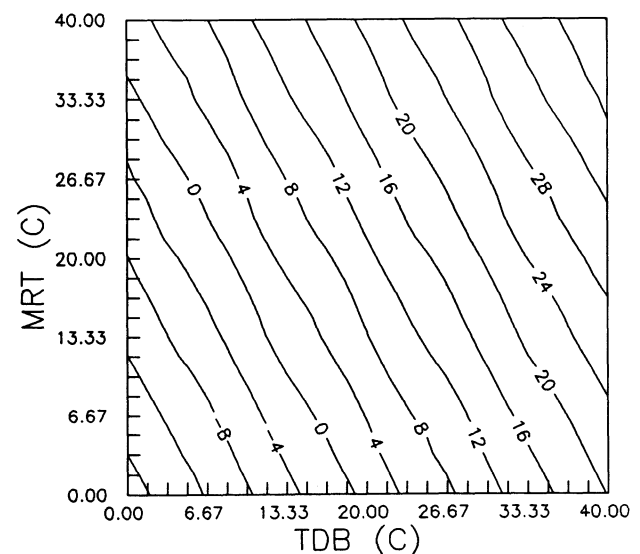


Figure 6—EET as a function of the mean radiant temperature and dry bulb air temperature at a free-stream velocity of 0.62 m/s.

which validating data was not available. These points are to be interpreted as extrapolated values.

Table 4 is divided into three main sections. Section 1 represents the hypothermic region for the newborn as suggested by Mount (1963 a, b). Section 2 represents the homeothermic region for the newborn. The PREFERRED portion of section 2 represents those EET values the newborn prefers (Mount, 1963a). For example, if the velocities are near still-air conditions (0.12 m/s), then a TDB and MRT of 30.0°C would result in an acceptable EET. However, if velocities were extremely high (0.72 m/s), the minimum TDB and MRT combination that would still produce an acceptable EET would be 35.0° and 30.0° C, respectively.

Figure 6 represents an EET chart for a free-stream velocity of 0.62 m/s. The MRT and TDB vary between 0.0 and 40.0° C. If for example, the ambient air temperature was 25° C and the radiant temperature was 20° C, the effective temperature felt by the newborn would be about 15° C. If an effective temperature of 25° C was desired, ambient air temperature would have to be raised to 35° C.

The EET can be used to assess thermal environment in farrowing units and to identify management strategies for reducing heat loss from newborns. For example, if zones of acceptable EET levels were defined corresponding to a newborn's survival and growth, then a calculated (or measured) EET for any environment could be compared against this standard, and environmental adequacy could be assessed. If the calculated EET lay outside this standard, then adjustments to either TDB, MRT, or air velocity conditions of the building could be adjusted to produce an acceptable EET and thermal environment.

Mount (1963 a, b) studied the level of TDB in a naturally convective, well-insulated environment preferred by the newborn. From these studies, he concluded that the survival temperature limits were between 5.0° and 38.0° C (Mount, 1963b) (Zone 1, fig. 7), but the preferred limits were between 29.0° and 34.0°C (Mount, 1963a) (Zone II, fig. 7) for piglets one to seven days old. The survival and preferred limits can be taken as the acceptable range of the EET because the TDB measurements recorded were in a well-insulated (MRT = TDB), naturally convective environment. This article assumes the above ranges;

however, it is recognized that further research may widen the acceptable range.

Also shown in figure 7 is the combined data from table 2 and the resulting regression line for the three studies. From figure 7, it was observed that two data points fell inside the preferred EET zone. For example, from Mount's (1966) study, the environmental condition with MRT = TDB = 30.0° C and velocity < 0.12 m/s produced an EET within zone II (EET = 30.0°C). Raising the velocity level to 0.34 m/s (at MRT = TDB = 30.0°C) produced an EET outside the preferred zone (EET = 27.5° C). Therefore, the increased velocity would require a higher MRT and/or TDB to compensate for added convective heat loss caused by increased velocity level. While zones I and II are approximate suggestions (Mount, 1963 a, b), they represent a qualitative representation of the changes needed in MRT, TDB, and air velocity to compensate for an EET outside the preferred zone.

## CONCLUSIONS

An effective environment temperature (EET) for newborn piglets was developed based on a description of radiative and convective heat loss. Based on the developed EET and the comparison with past calorimetric studies, the following conclusions can be drawn:

1. The developed EET successfully described radiative and convective environments to which the newborn piglet was subjected.
2. Correlations with past heat loss studies indicated that coefficient of determination values ranged between 0.87 and 0.98. Correlations with the complete data set indicated a coefficient of determination of 0.91.
3. In limited calorimetric studies presented with sensible heat loss calculated as a function of varying environmental parameters (MRT, TDB, and velocity), there appears to be a good correlation between measured sensible heat loss and effects of the environment as described by EET given in equation 14.

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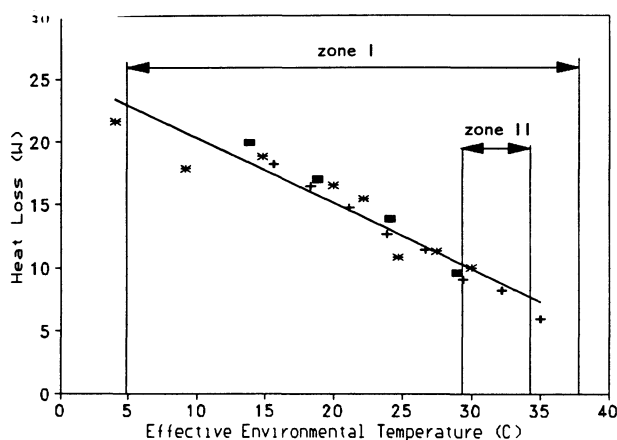


Figure 7—EET vs. heat loss for the combined data set and Zones I and II as suggested by Mount (1963a, b).



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## NOMENCLATURE

A	= parameter used in the EET	(m <sup>2</sup> -C/W)
B	= parameter used in the EET	(m <sup>2</sup> -C/W)
D	= characteristic diameter of the newborn	(m)
F	= thermal radiation shape factor	(dimensionless)
g	= gravitational constant	(m/s <sup>2</sup> )
Gr	= Grashof number	(dimensionless)
h	= heat transfer coefficient	(W/(m <sup>2</sup> -C))

$\bar{h}$	= average heat transfer coefficient	(W/(m <sup>2</sup> -C))
k	= thermal conductivity (air and hover)	(W/(m-C))
Pr	= Prandtl number	(dimensionless)
Q	= sensible heat loss (radiation + convection)	(W)
R	= thermal resistance	(m <sup>2</sup> -C/W)
T	= temperature	(C)
TDB	= dry bulb air temperature	(C)
U	= velocity	(m/s)

## GREEK

$\nu_f$	= fluid (air) kinematic viscosity	(m <sup>2</sup> /s)
$\beta$	= thermal coefficient of expansion	(1/° K)

## SUBSCRIPTS

absolute	= absolute temperature
actual	= the actual convective coefficient
ADBT	= adjusted dry bulb temperature
c	= convection
core	= newborn's deep-body core temperature
d	= based on characteristic diameter
EET	= effective environment temperature
f	= property evaluated at the film temperature forced convection conditions
MAT	= modified ambient temperature
MRT	= mean radiant temperature
n	= particular surface within the enclosure
natural	= natural convective coefficient newborn
newborn	= signifies surface of the newborn
o	= operative temperature
r	= thermal radiation
t	= subcutaneous tissue of the newborn
$\infty$	= property evaluated at the free-stream conditions